The Astrodynamics of New Planetary Systems, W. D. Kelly,

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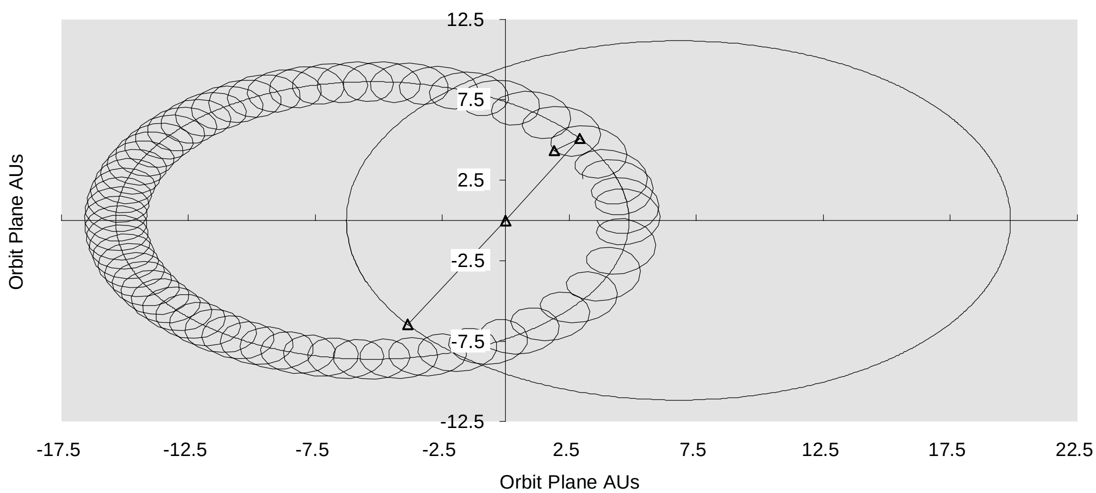
Search for extra-solar planet orbits stable for life resembles satellite mission orbit selection. For the extra-solar problem, the analyst deals with gravity and radiation fields of the primary and, in many cases, a perturbing secondary body, whether binary star, giant (jovian) planet or brown dwarf. Beginning in 1985, we analyzed planetary stability for nearby binary (α Centauri, Sirius, Procyon) systems [**1,2**] as a Restricted Elliptic 3-Body Problem (RE3BP), where mean stellar separations ~25 AU and system eccentricities **e** ~0.5 (e.g., Fig.-1). Hypothetical planets in orbits thermally analogous to Earth's, plus planets in other temperature zones, were initialized and tracked for 10^3-10^5 years. Results indicate that secondary stars perturb nominally circular, co-planar planet orbits at stellar pericentron passage, causing planet **e** and angular momentum to cycle over thousands of years as planetary periastron $\boldsymbol{\omega_p}$ processes. With recent doppler and visual observations [**3-6**] detecting jovian or brown dwarf partners to stars at radii where terrestrial planets were preferred (47 Ursae Majoris, 70 Virginis, 51 Pegasi, Gliese 239), RE3BP studies include new cases and data. Since accelerations ~ M/R^2, effects for the first two "planetary" cases, despite less mass, were similar to "stellar" examples due to closer proximity. Comparisons of several binary systems show that regions where planets are unstable, or ejected from the system, vary in orbit radius effective temperatures ($\mathbf{T_{eff}}$), affecting available protoplanetary chemical constituents. Stable orbit regions also possess many quantum-like properties in phase diagrams. Thus, terrestrial planets, if extant near binaries, experience (in 4th order Runge-Kutta integration, RE3BP) complex climate cycles influenced by secondary bodies. Observed environmental factors provide different formation circumstances, whether processes are accelerated or inhibited.

Fig.-1 α Centauri A & B, A with Planet Track
Ma=1.1, Mb=.85, La=1.5, e*=.52, P*=79.9yr, Mean Sep=23.4au, Epoch=1,500d



The tables summarize RE3BP plots for 3 nearby binary systems, Jupiter-Sun and newly discovered systems with jovian or brown dwarf components: Table-1, stability changes with respect to $\mathbf{T_{eff}}$ at radius **R**; Table-2, stellar system inclination effects (0^o at orbit plane normal aligned to line of sight). For **e** and $\boldsymbol{\omega_p}$ cycles, semi-major axes remained steady after initialization with no significant variation over simulation periods. Mass and luminosity of stellar components are implicit in tables, but published estimates vary due to parallax, element abundance and age assumptions. Since several planet simulation methods are now employed (n-body, RE3BP, symplectic, Runge-Kutta), we suspect that **e** and $\boldsymbol{\omega_p}$ cycle comparisons will be necessary to evaluate system stability as a function of simulation scheme as much as stellar dynamics.

Table -1 Planetary Orbits at Control Volume Temperature Radii from Binary Stars

Star System Component	T_{eff} (^oK)	Nominal Radius (AUs)	2-body Period (days)	Ejection (yrs)	Eccentricity Cycle Period (10^3yrs)	Eccentricity Cycle Magnitude (ΔR/Ro)
α	400	1.2468	484		8.0	0.08, -0.09
Centauri	350	1.6285	724		5.0	0.11, -0.12
A	300	2.2165	1,149		2.6	0.12, -0.15
	275	2.6368	1,492	-	1.8	0.13
	250	3.1918	1,985	-	-	-
	225	3.9405	2,724	2,500	-	-
Procyon -	400	2.4517	1,075	-	1.5	0.12, -0.18
α Canis	350	3.2022	1,605	-	-	-
Minoris A	300	4.3586	2,549	2,000	-	-
Sirius - A	400	4.882	2,870	550	-	-
Sun with	400	1.000 (Earth)	365		180	0.023, -0.023
Jupiter	327.5	1.518 (~Mars)	684		88	0.035, -0.035
(RE3BP)	250	2.606	1,536	-	>8.0	>0.05
	200	4.072	3,001	-	4.5	0.065
		[ejections around Jupiter @5.2 AU]				
	150	7.239	7,113	-	1.0	0.17, -0.23

Table -2 M_b sin i Contours for Spectroscopic Binary Systems

Star System Component	T_{eff} (^oK)	Nominal Radius (AUs)	2-body Period (days)	Ejection (yrs)	Eccentricity Cycle Period (yrs)	Eccentricity Cycle Magnitude ($\Delta R/R_o$)	LOS Inclin (deg)
70	400	1.7332	717	-	3450	0.23, -0.3	90
Virginis A				-	2400	0.24, -	45
				-	1500	0.25, -	30
				-	400	0.25, -0.4	15
70 Vir. B	n/a	400,000 km	0.85	-	41	.0065, -.007	90
47	400	1.204	547	-	43.8	0.12. -0.15	90
Ursae				-	30	0.12	45
Majoris A				-	18	0.12, -0.24	15

References: **[1]** Kelly, W. D., "Planetary Motion about Nearby Binary Star Systems with Restricted Elliptic Three Body Motion", (1986), *Journal of the Astronautical Sciences*, v. 34, n. 2. **[2]** —, "Planetary and Dust Particle Orbits about Binary Stars: Radiation Effects", AIAA 88-4261, AIAA-AAS Astrodynamics Conf. Proc., Aug. 1988. **[3]** Marcy, G. W., Butler, R. P., "A Planetary Companion to 70 Virginis", *The Astrophysical Journal Supplement*, 20 June 1996. **[4]** —,"A Planetary Companion to 47 Ursae Majoris", *ibid*. **[5]** Butler, R P. et al., "Attaining Doppler Precision of 3 m/s", *Pub. Astronomical Society of the Pacific*, v. 108, pp. 500-509, June 1996. **[6]** Beckwith, S. V., Sargent, A. I, "Circumstellar Disks and the Search for Neighboring Planetary Systems", *Nature*, v. 383, p. 139, 12 Sept 1996.